A Highly Sensitive Strain Sensor Using Surface Acoustic Wave and Its Evaluation for Wireless Battery-less Sensor Network

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A Highly Sensitive Strain Sensor Using Surface Acoustic Wave and Its Evaluation for Wireless Battery-less Sensor Network

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Abstract

This paper descries a highly sensitive stain sensor using surface wave (SAW) for battery-less wireless sensor network. A SAW strain sensor measuring method by observing a shift of a resonant frequency was fabricated and numerically discussed. The SAW strain sensor having 40MHz resonant frequency was designed and fabricated onto a Quartz crystal substrate by micromachining. Tensile testing was carried out using a specimen made of SS400 as a test piece. Detectable strain of the sensor is below 10^{-5} orders. Since the resolution of frequency in our measurement system in the test was 100Hz, this result is correct in theoretically. This result shows our sensor sensitivity based on theory will be up to 10^{-8} orders in the case of the resonant frequency 1GHz and the resolution frequency 1Hz.

I. INTRODUCTION

A ubiquitous network system including a RF-ID system and a sensor network is expected as an infrastructure of various services and industries from the points of view of the application in the fields of society, security, medicine, welfare, and so on.

Especially strain of structure will give important information for preventing disaster and for maintaining infrastructures. For instance to avoid dangers by earthquakes and aged deteriorations, it is important to monitor strain changes of structures such as the second piping of nuclear reactor, water supply, sewerage systems, bridges and expressways, etc. So, a highly sensitive strain sensor combined with an active wireless tag to transmit strain information will very useful to manage many infrastructures safely.

For networking these sensors, many applications as ubiquitous services will be offered. Since we don't have sensors adaptable to sensor network of ubiquitous services sensor network service is rarely realized right now. There are some problems for the sensor network. For instance, cost, reliability, and power supply of sensors in the case of wireless network must be difficulties.

We are studying to solve for such kinds of problems from the points of views of cost, wireless and powers supply. Since SAW sensor offers variety of wireless measurements requiring no internal power supply, SAW sensor is suitable for battery-less sensor network. We have chosen a strain sensor using SAW as a first choice of a sensor for the sensor network.

In this work, a shift of resonant frequency of SAW was analyzed when stress was applied in the Interdigital Transducer (IDT) area, although in literature [1], a strain sensor using SAW detected traveling time between the components. A SAW strain sensor measuring a shift of a resonant frequency was fabricated and numerically discussed. And a circuit for detecting a shift of a resonant frequency was discussed.

II. EVALUATION OF MEASURING METHOD

Fig.1 shows a schematic diagram of our wireless battery-less SAW sensor network system. The sensor is made of a piezoelectric crystal substrate, a single-port SAW resonator with an inter-digital transducer that is connected to an external antenna.

The relationship between the resonant frequency and the strain is shown in Fig 2. The measuring resolution of frequency was assumed to be 0.1Hz. If the resonant frequency is 1GHz, it is able to detect the strain up to 10^{-10} orders. The strain sensor has obviously highly sensitivity compared with present semiconductor strain sensors. Their detecting sensitivity is usually 10^{-5} orders.

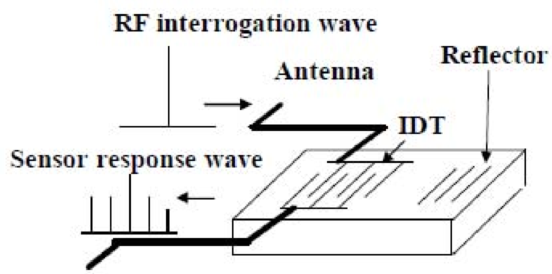


Figure 1. Schematic diagram of wireless battery-less SAW strain sensor.

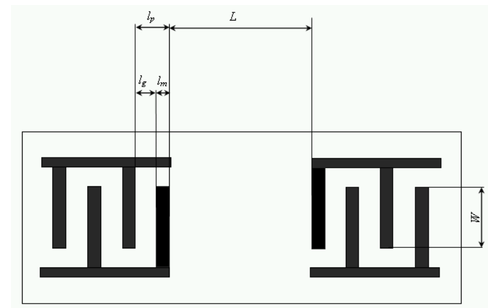


Figure 4. SAW design.

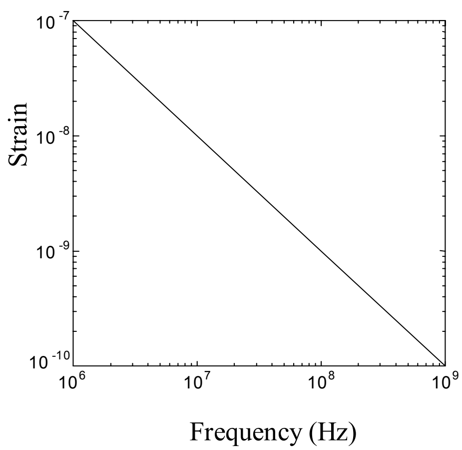
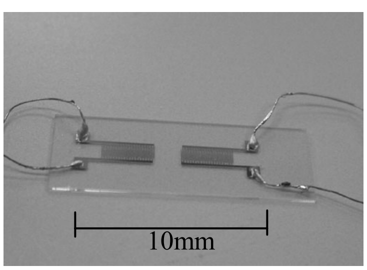


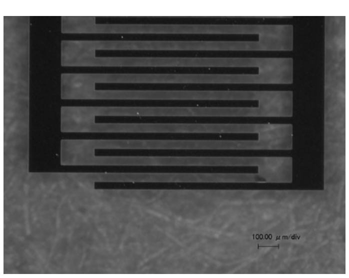
Figure 2. Relationship between resonant frequency and strain of the sensor using SAW.

TABLE I. DESIGN PARAMETERS

f (MHz)	40
v (m/s)	3158
λ (μm)	79
l_m (μm)	20 (0.25λ)
l_g (μm)	20 (0.25λ)
L (μm)	1579 (20λ)
W (μm)	790 (10λ)
n (pair)	20



(a) Photograph of the fabricated sensor.



(b) Magnification image of IDT.

Figure 3. Fabricated SAW strain sensor.

The strain sensor device was designed and fabricated based on results of the theoretical analysis as shown in Fig.3. An AT cutting crystal having less temperature dependence was used as a substrate. The resonant frequency was 40 MHz. The parameter of the SAW device is shown in Fig.4 and Table 1.

Tensile testing was carried out using a specimen made of SS400 as a test piece based on JIS standardization to evaluate the sensor. The thickness of the test piece is 1.6mm. The strain sensor was put on one side of the test piece and a commercial type strain gauge was put on the other side as shown in Fig. 5. The bridge box in which a Wheatstone bridge was built in was connected to the strain gauge.

Changing the load ranging from 0 N to 1000 N tensile test results were shown in Figs. 6. It was proved that the values of strain measured by our sensor are almost consistent with the theory values respectively. The detectable strain of the sensor is 10^{-5} orders. Since a slip at the adhesion layer between the sensor and the SS400 specimen seemed to be caused, in the case of larger load ranging from 600N to 1000N, the experiment values were smaller than that of the theory.

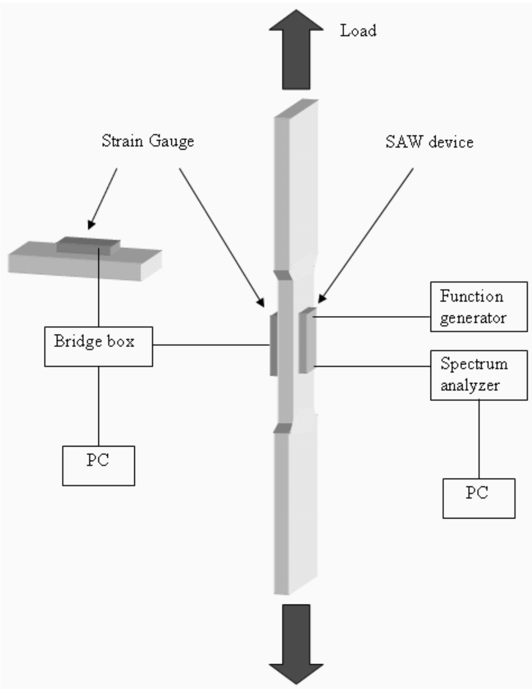


Figure 5. Tensile test piece with strain sensors setup.

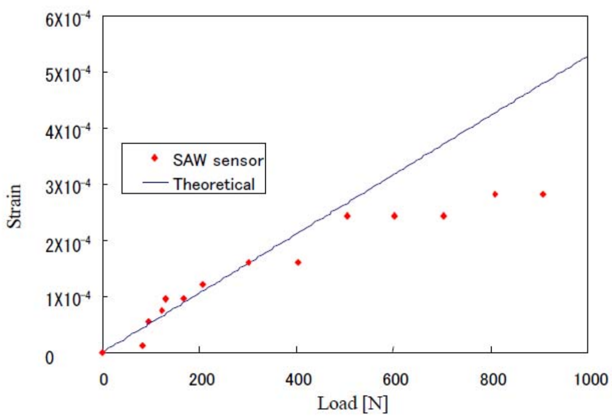


Figure 6. Tensile test ranging from 0N to 1000N.

III. BASIC STUDY OF A DETECTIVE CIRCUIT

To detect the shift of a resonant frequency, we have studied circuit architecture.

Fig.7 shows a block diagram of our sensor module system. Two SAW devices use for oscillator source, one for strained and the other for no strained. To fabricate two SAW devices using same mask pattern, to package two oscillator circuit in same package, there is no need for calibration caused by fabrication accuracy, electronics device accuracy, and negative effect of a thermal.

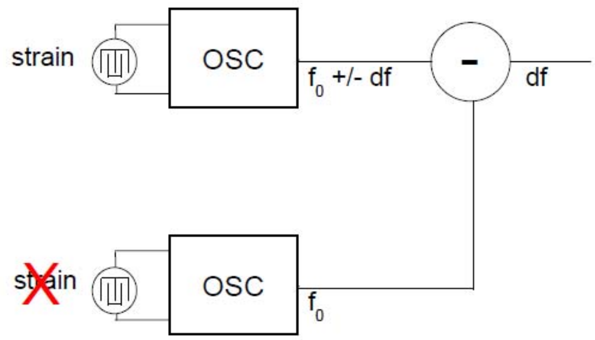


Figure 7. Block diagram of sensor module system.

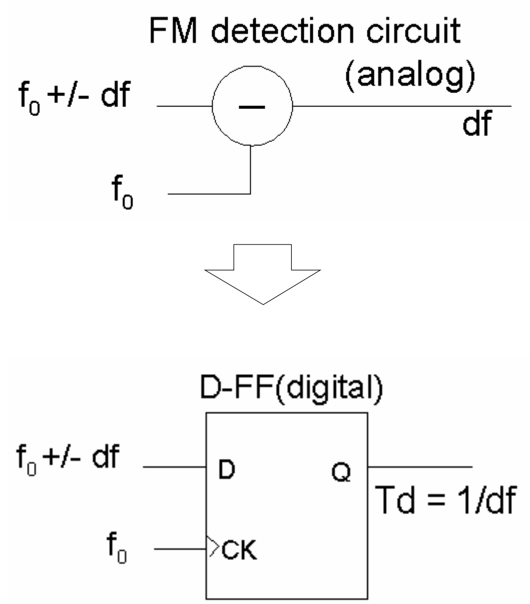


Figure 8. Principle to detection.

Fig.8 shows a principle to detect the difference of two resonant frequencies. Instead of FM detection circuit, Delay Flip-Flop (D-FF) can be able to detect the difference of two resonant frequencies direct. Fig.9 shows a timing chart to detect the difference of two resonant frequencies. We can get Td cycle digital wave at Q. Here Td is 1/df.

By using D-FF, the simple detective circuit leads the reduction of the cost and power consumption of the sensor.

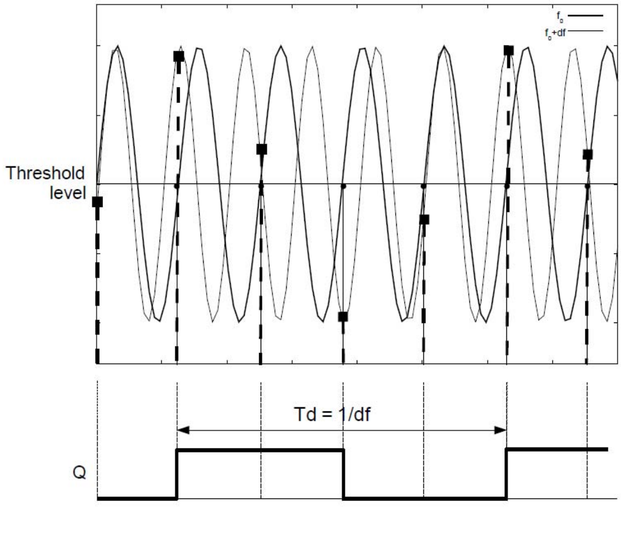


Figure 9. Timing chart.

IV. Conclusion

A SAW strain sensor measuring a shift of a resonant frequency was fabricated and numerically discussed. And a circuit to detect a shift of a resonant frequency was discussed.

- The strain sensor device using SAW device with new principle for the ubiquitous network was designed and fabricated by using micromachining technique.
- It was shown to be able to achieve a highly sensitive sensor by measuring the change in the resonance frequency of the surface acoustic wave element in theory.
- By the tensile testing, it becomes clearly that this sensor can detect 10^{-5} orders strain. Since the resolution of frequency in our measurement system in this test was 100 Hz, this result correct in theoretically.
- Using two SAW devices use for oscillator source, calibration less detective circuit is possible.
- By using D-FF, the simple detective circuit leads the reduction of the cost and power consumption of the sensor.

References

[1] Vasundara V Varadan, Vojay K Varadan, Xiaoqi Bao, Srinivasam Ramanathan and Daniel Piscotty, Smart Mater. Struct. 6, 745-751, 1997.